doi: 10.1590/S0100-83582016340400005

Partitioning of Competition for Resources Between Soybean and Corn as Competitor Plant[1]

Partição da Competição por Recursos entre Soja e Milho Como Planta Competidora

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ABSTRACT - Plants compete for resources present below and above the soil surface. The objective of this work was to separate the individual effects of the competition for resources between soybean and corn as competitor plants. The experiment was conducted in a greenhouse, in 2014/2015. The treatments consisted of soybean cultivars (TEC 5718 and TEC 6029) in competition conditions with corn (no competition, competition for soil resources, competition for solar radiation and total competition). The variables evaluated were plant height at 7, 14, 21, 28, 35 and 42 days after emergence (DAE), stem/culm diameter, leaf area, shoot dry mass, root dry mass and the chlorophyll index, at 42 (DAE). The competition for soil resources between soybean and corn is pronounced, being that short cultivars with determinate growth habit, such as TEC 5718, invest more in root biomass, specific leaf area and leaf area ratio when in competition. The soybean cultivars do not suppress corn, but allow it to benefit when associated to its root system, increasing the shoot and root dry mass, leaf area and chlorophyll index.

Keywords: *Glycine max*, *Zea mays*, water, competitiveness, solar radiation, competitor plant.

RESUMO - As plantas competem por recursos presentes abaixo e acima da superfície do solo. O objetivo deste trabalho foi separar os efeitos individuais da competição por recursos entre a soja e o milho como planta competidora. O experimento foi conduzido em casa de vegetação, em 2014/15. Os tratamentos consistiram de cultivares de soja (TEC 5718 e TEC 6029) sob condições de competição com milho (ausência de competição, competição por recursos do solo, competição por radiação solar e competição total). As variáveis avaliadas foram estatura de plantas, aos 7, 14, 21, 28, 35 e 42 dias após a emergência (DAE), diâmetro do caule/colmo, área foliar, massa seca da parte aérea, massa seca radicular e índice de clorofila, aos 42 DAE. A competição por recursos do solo entre a soja e o milho é pronunciada, sendo que cultivares de baixa estatura e de hábito de crescimento determinado, como TEC 5718, investem mais em biomassa de raízes, área foliar específica e razão de área foliar quando em competição. Os cultivares de soja não suprimem o milho, e sim permitem que este se beneficie quando associado ao seu sistema radicular, aumentando a massa seca da parte aérea e radicular, a área foliar e o índice de clorofila.

Palavras-chave: *Glycine max*, *Zea mays*, água, competitividade, radiação solar, planta competidora.

INTRODUCTION

The environmental resources, such as water, nutrients and solar radiation, are the main ones involved in the competition between plants. However, the relative importance of these different conditions in the competition varies according to the involved species (Bianchi et al., 2006).

Plants perceive light through specific photoreceptors, including phytochromes, cryptochromes and phototropins, which induce photomorphogenic responses that influence the investment pattern of the resource that is being captured and the ability of the plants to capture additional resources (Ballaré, 2014). The reduced relationship of the red (V)/ extreme red (Ve) wave lengths, through a

[1] Recebido para publicação em 21.3.2016 e aprovado em 4.4.2016.
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change in the quality of light, detected mainly by phytochromes, has an important role as the induction of several morphological changes in the architecture of plants, mainly: reduction on the number of branches and leaves, reduction of the shoot/root relationship and stem blanching (Ballaré, 2014).

The competition for nutrients is affected by the water content on the soil, by specific aspects of the competitors, as well as by the differences on the growth habit and demand for nutrients by the involved species (Pitelli, 1985). The relationship between the ability of the plant to capture nutrients from the soil and the required amounts, varies not only according to the cultivar, but also according to the degree of competition (Cury et al., 2012).

When soybean plants are under competition, they adjust their growth according to the established population of the crop, the occurring weeds and the environmental conditions, such as solar radiation, humidity and level of nutrients on the soil (Silva et al., 2009). It is understood that the available resources on the environment are used by plants according to their abundance, as well as their ability to capture them.

With the commercial release of genetically modified corn to resist to the glyphosate herbicide (RR), remaining seeds on the soil have infested soybean cultivated in succession. Since corn is a high plant, whose architecture is different from the architecture of soybean, its occurrence has caused damages, showing its high competitiveness and, therefore, demanding its control with the use of alternative herbicides to glyphosate for its management, since soybean is also RR. The presence of two to four corn plants per m^2, for example, reduced in up to 50% the productivity of soybean (Embrapa, 2013).

Although the occurring competition is integrated, studies that isolate the factors favor the understanding of the competition mechanisms (McPhee and Aarssen, 2001). For such, regardless of the adopted methodology, it must offer the complete separation of each factor, physically isolating the effects with the use of partitions. The main partition methods used for studies under controlled conditions are: divided pot, plant row and target plant (McPhee and Aarssen, 2001). On the three methods, four competition situations are created: no competition, competition for soil resources only, competition for solar radiation only, and competition for both resources.

The plant row technique consists in studying the competition between the plants, which are arranged in rows, in such a way that one row from one species competes with one row from the other species, allowing the comparison of the competition between species; however, total competition occurs within the same species (McPhee and Aarssen, 2001). According to these authors, this technique allows the adequate separation of the competition that occurs beneath and above the soil surface, indicating which fraction offers greater competitiveness to the plants.

The objective of this study was to separate the individual effects resulting from the competition for soil resources and/or solar radiation, between soybean cultivars and corn a competitor plants.

MATERIAL AND METHODS

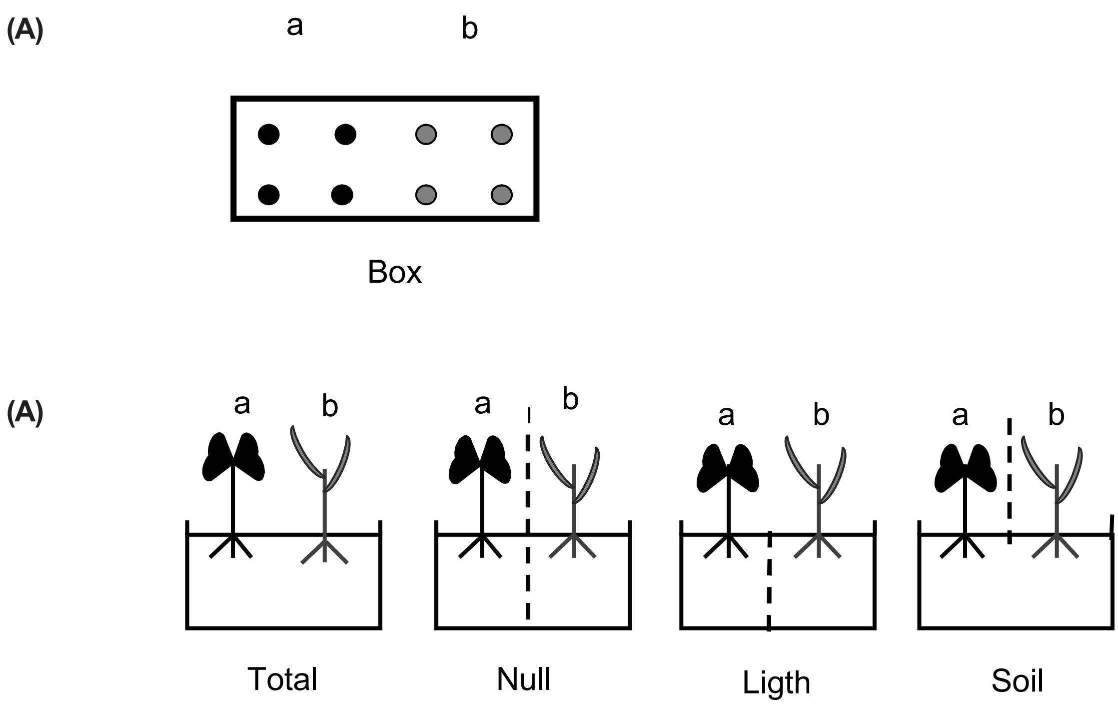
The experiment was conducted in a greenhouse of Faculdade de Agronomia Eliseu Maciel, at Universidade Federal de Pelotas – FAEM/UFPel, during the 2014/2015 crop season. The plant row method was used, with the use of lateral divisions, allowing the isolation of the plants according to each studied treatment. Two soybean cultivars were evaluated: TEC 5718IPRO (low plant height, early cycle and determined growth habit) and TEC 6029IPRO (medium/high plant height, early cycle and undetermined growth habit), in relation to the competition with corn as a competitor plant (F2 population of the AG7000YGRR2 hybrid).

The experimental design was completely randomized, on a 2x4 factorial, where the treatments consisted in the combination of the two soybean cultivars under four competition conditions with corn [no competition (Null), competition for soil resources + solar radiation (Total), competition for soil resources only (Soil) and competition for solar radiation only (Light)], with four replications.

The experimental units were constituted by plastic boxes with 0.24 x 0.55 m of surface and 0.16 m of height (area = 0.132 m^2 and volume = 0.021 m^3), filled with 18.5 kg of soil from the agricultural area, classified as Red-Yellow Argisol, with a sandy loam texture. Soybean and corn were sown on two parallel rows (Figure 1), with four plants per row, where two were soybean and two were corn plants, totaling eight plants per box (61 plants m^{-2}). For the separation of the plant rows in order to isolate the competition on the shoot, wooden divisions were used coated with an aluminum film. In order to isolate the competition for soil resources, the boxes also received a wooden division, and they were sealed with silicone. The seeds were positioned 4 cm deep, with the thinning of the excess of seedlings, remaining the most vigorous ones, 10 days after sowing (DAS).

At 7, 14, 21, 28, 35 and 42 days after emergence (DAE), the plant height was determined on the competitors (EP). At 42 DAE, the stem/culm diameter (DC), chlorophyll index, leaf area (AF), shoot dry mass (MSPA) and root dry mass (MSPR) of the soybean and corn plants were determined, as well as the soybean stage. For soybean, the leaf mass ration (RMF), specific leaf area (AFE) and leaf area ratio (RAF) variables were also measured, using the following equations (Radosevich et al., 1997): RMF = MF/MSPA, AFE = AF/MF and RAF = AF/MSPA; where MF = leaf dry mass. With these variables, an attempt was made to indicate the allocation of photoassimilates through the leaf ratio (RMF and RAF) and the specific leaf expansion (AFE).

The results were verified accordings to their normality, using the Shapiro-Wilk test, with no need for transformation. Then, it was conducted the analysis of variance, according to the F test ($p \leq 0.05$); in case of significance, the means were compared by Tukey's test ($p \leq 0.05$) for the competition conditions, and for the comparisons among cultivars, the t test was used ($p \leq 0.05$).



Letter "a" represents the row of soybean plants, and letter "b", corn as the competing plant. (Adapted from: Mcphee and Aarssen, 2001; Bianchi et al., 2006).

Figure 1 - Distribution scheme of the plants in plastic boxes (A) and position of the divisions (traced lines), according to the studied treatments (B).

RESULTS AND DISCUSSION

There was no significant interaction for soybean EP on the evaluated times, except for 21 and 28 DAE (Table 1). The highest values, on average, were for cv. TEC 6029, and this result was expected, since it shows a medium/high height in comparison to TEC 5718.

In relation to the competition conditions, at 7 and 14 DAE, no difference was observed among the treatments; at 35 DAE, EP was higher when the soybean plants grew free from any type of competition in comparison to the competition for soil resources. However, there was no difference in relation to the total competition condition or the competition for solar radiation (Table 1). The dispute was more intense for this variable when there was competition for soil resources in isolation, where soybean plants showed the lowest EP, but did not differ in relation to the other forms of competition.

Table 1 - Height (EP) at 7, 14, 35 and 42 days after emergence (DAE) of soybean plants, cv. TEC 5718 and TEC 6029, when in competition with corn for environmental resources. AEM/UFPel, 2014/15

Cultivar	EP (cm)			
	7 DAE	14 DAE	35 DAE	42 DAE
TEC 5718	7.57 *	11.05 *	25.40 *	33.37 *
TEC 6029	8.41	12.22	29.05	38.19
Mean	7.99	11.64	27.22	35.78
VC (%)[1/]	8.59	6.28	11.08	11.79

Competition conditions	EP (cm)		
	7 DAE	14 DAE	35 DAE
Null	8.64 a	12.40 a	30.80 a
Total	7.59 a	11.31 a	26.43 ab
Solar radiation	7.83 a	11.20 a	26.47 ab
Soil	7.91 a	11.55 a	25.19 b
Mean	7.99	11.64	27.22
VC (%)[1/]	8.59	6.28	11.08

[1/] Variation coefficient. * Significant according to the t test ($p \leq 0.05$). Means followed by different letters differ from each other according to Tukey's test ($p \leq 0.05$).

For soybean, at 21 and 28 DAE, the interaction among the studied factors was observed, and, in that case, regardless of the condition, the competition for environmental resources reduced the height of TEC 6029 on both evaluation times (Table 2). For the TEC 5718 cultivar, no significant difference was observed among the studied conditions. Considering this fact, it is possible to infer that TEC 5718 kept its growth unchanged even under different forms of competition, differently from TEC 6029, which was sensitive to the competition conditions, reducing EP. The EP reduction of TEC 6029 indicated that there was a higher niche overlap with corn, competing for the environmental resources.

When subject to different competition conditions at 21 and 28 DAE, EP of the cultivars was equivalent (Table 2). Although for TEC 6029 a higher EP was observed in relation to TEC 5718, when free from competition, the cultivars were equivalent when exposed to the different levels of competition. Therefore, the competition with corn compromised the EP growth of TEC 6029, and the fact that it has a medium/high height with an undetermined habit did not offer advantages in relation to TEC 5718, with low height and determined habit.

Table 2 - Height (EP) at 21 and 28 days after emergence (DAE) of soybean plants, cv. TEC 5718 and TEC 6029, when in competition with corn for environmental resources. FAEM/UFPel, 2014/15

Competition condition	EP (cm)			
	21 DAE		28 DAE	
	TEC 5718	TEC 6029	TEC 5718	TEC 6029
Null	15.10 Ab	20.37 A a	19.16 A b	25.94 A a
Total	15.74 A a	16.42 B a	18.67 A a	20.72 B a
Solar radiation	14.36 A a	15.85 B a	17.61 A a	20.09 B a
Soil	14.90 A a	15.80 B a	18.46 A a	18.97 B a
Mean	15.03	17.11	18.58	21.43
VC (%)[1/]	7.46		8.90	

[1/] Variation coefficient. Means followed by different uppercase letters, on the rows, differ from each other according to Tukey's test ($p \leq 0.05$), and means followed by different lowercase letters, on the rows, differ from each other according to the t test ($p \leq 0.05$).

Corn shows advantages due to the fact that it has a canopy architecture, differently from soybean, conferring it a higher competitive ability, reducing the quality of the light on the neighboring plants. In addition, corn is a C4 plant, and it has a rather developed root system. It is likely that the impact caused by voluntary and/or spontaneous corn on soybeans is related to the direct competition for light, due to its higher height, causing a high suppression on the crop (Marquard et al., 2012).

For the corn EP, there was no significant interaction among the factors, nor an isolated significance for them across all evaluated times (data not shown). For soybean DC, no significant interaction was observed among the soybean cultivar factors and the competition conditions, and a significance was observed only for the competition conditions; in that case, DC was higher, on average, when the competition was null (Table 3). For corn DC, there was no interaction among the factors, and no isolated significance was observed for them (data not shown), inferring that the competition with the soybean cultivars under different competition conditions did not change the DC of the coexisting corn.

Regardless of the condition, the competition for environmental resources reduced the AF of soybean cultivars (Table 3). The competition that occurred underneath the soil surface and the total competition, reduced the AF increase of the soybean plants in 38 and 40%, respectively. Also, they were higher than the competition for solar radiation only, where there was a reduction of 20% in comparison to the condition where the competition was null. Although a statistical significance was observed for the soybean RAF, the competition conditions did not differ.

The proximity of plants from different species, as well as from the same species, results in competition for the amount and quality of light, and damages may occur in relation to the leaf area increment, with the possibility of interference in the formation and growth of the leaves (Wu et al., 2012). The low leaf area for soybean plants when they competed for soil resources and solar radiation (total) and for soil only, suggests that the competition was unsuccessful beneath the soil, and this reduces the competitive capacity of the shoot, since an increase on the allocation of biomass to the radicular system may have occurred, compromising the allocation to the shoot.

The competition condition factor was not significant for AFE; however, TEC 5718 showed greater leaf expansion per mass unit (AFE), corresponding to 12% more in relation to TEC 6029 (Table 3). In addition, the RAF of TEC 5718 was 11% higher due to the occurrence of plants with more leaves.

Table 3 - Stem diameter (DC), leaf area (AF), leaf area ratio (RAF), specific leaf area (AFE) and leaf area ratio (RAF) of soybean plants, cv. TEC 5718 and TEC 6029, when in competition with corn for environmental resources, 42 days after emergence (DAE). FAEM/UFPel, 2014/15

Competition condition	DC (mm)	AF(cm^2 per plant)	RAF (cm^2 g^{-1} of plant)
Null	4.95 a	613.57 a	147.92 a
Total	4.10 b	366.42 c	138.10 a
Solar radiation	4.17 b	492.43 b	155.06 a
Soil	4.19 b	383.37 c	148.09 a
Mean	4.35	463.94	147.29
VC (%)[1/]	9.00	12.19	7.31

Cultivar	AFE (cm^2 g^{-1} of leaf)	RAF (cm^2 g^{-1} of plant)
TEC 5718	287.10 *	155.88 *
TEC 6029	253.62	138.71
Mean	270.36	147.29
VC (%)[1/]	7.09	7.31

[1/] Variation coefficient. * Significant according to the t test ($p \leq 0.05$). Means followed by different letters differ from each other according to Tukey's test ($p \leq 0.05$).

Therefore, TEC 5718 created broader and thinner leaves (greater AFE) and developed a higher RAF, when compared to TEC 6029, which may be associated to the higher phenotypical plasticity; shading makes leaves expand more per mass unit, resulting in larger but thinner leaves (Radin et al., 2004). Soybean cultivars competing during the vegetative growth period with turnip plants resulted in an increase of the specific leaf area (AFE) and the leaf area ratio of soybeans (RAF) (Bianchi et al., 2006).

No significance was observed in relation to the competition conditions, nor between the soybean cultivars, for chlorophyll, ED and EP at 42 DAE, as well as for AFE and RMF. At 42 DAE, the soybean plants were on the R_1 stage, and the ED of the cultivars was not affected by the imposed competition conditions.

There was no significant interaction of the MSPA of soybeans and corn as the competitor plant, among the evaluated factors, and only their isolated significance was observed (Figure 2A, B). Among the soybean cultivars, TEC 6029 showed higher MSPA, producing 27% more (Figure 2A). With corn plants, there was no significant difference when they grew with cultivars with different characteristics (Figure 2B). Morphological characteristics, such as the higher MSPA increment in initial stages, are interesting, since they allow a faster occupation of the space and, therefore, imply high possibilities of suppressing the growth of competitor plants. It is known that there is some variability between the soybean cultivars in relation to their competitive ability. Among the morphological characteristics that assign higher competitiveness to cultivars, the shoot dry mass production is majorly important (Lamego et al., 2005).

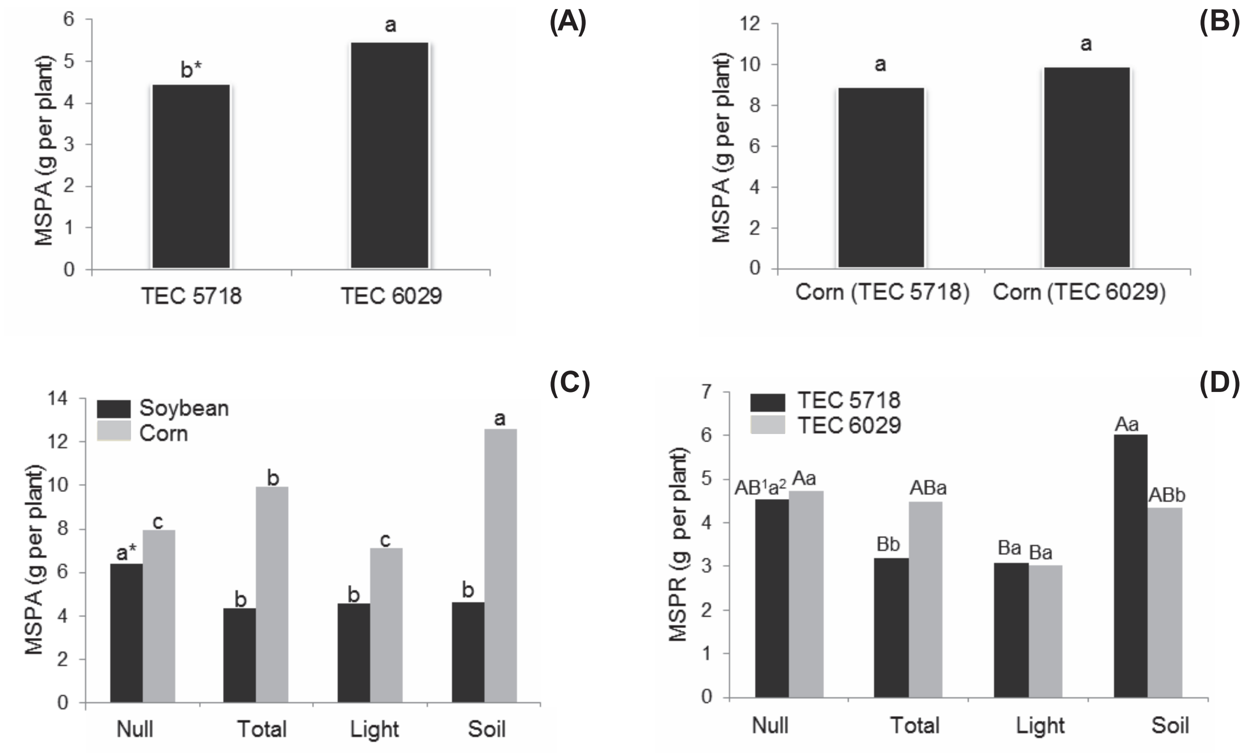
For soybean, the null competition condition allowed a greater production of MSPA (Figure 2C). The MSPA losses correspond to 32% (total competition), 28% (competition for solar radiation) and 27% (root competition), when compared to the condition in which there was no competition.

The corn MSPA was higher when it competed only for soil resources against the soybean cultivars, and an increase of 37% was observed, when compared to corn growing in isolation (null competition) (Figure 2C). In case of total competition, the MSPA production of corn was 20% higher, in comparison to the null competition. Therefore, it is inferred that corn benefited when it was associated to the root system of soybeans, and an increase was observed on its MSPA. The nitrogen biological fixation capacity of soybeans may have favored corn, making the nutrient available on the soil, since its growth upon the presence of soybeans was higher in comparison to when it grew in isolation. A similar result was observed by Bianchi et al. (2006), when turnip grew in competition for soil resources with soybeans.

The MSPR variable of soybean showed an interaction among the factors (Figure 2D). TEC 5718 showed the lowest production of MSPR when in total competition (3.19 g per plant) and upon the competition for light (3.08 g per plant) against corn. The higher production of MSPR for this cultivar occurred upon the competition for soil resources (6.03 g per plant), which did not differ from the null competition. Under conditions in which there is the presence of neighboring plants, the plants perceive it, and the root system is able to develop in order to allow a greater increment of root dry mass, occurring more in the direction of the neighboring plant than of its own roots (Bianchi et al., 2006). A process occurs in which the plant avoids its own roots, and this allows them to minimize waste in the allocation of carbohydrates, in order to overcome the competition against itself (Falik et al., 2003).

As the competition on the root region is perceived, the plant invests on roots, aiming at occupying the soil spaces more quickly and increasing the allocation of biomass to the root system (O'Brien et al., 2005). The high production of MSPR when the TEC 5718 cultivar competed only for soil resources may be associated to the perception of future competition and, consequently, it must promote a greater allocation of biomass to the root system when in the presence of competing corn plants.

Plants of TEC 6029 cultivar produced numerically less MSPR when in competition only for light (3.03 g per plant), but they did not



Means followed by different letters differ from each other according to the t test (p≤0.05). [1]Means followed by different uppercase letters compare the conditions that differ from each other according to Tukey's test (p≤0.05). [2]Means followed by different lowercase letters compare cultivars that differ from each other according to the t test (p≤0.05).

Figure 2 **-** Shoot dry mass (MSPA) 42 days after emergence (DAE): of soybean plants, cv. TEC 5718 and TEC 6029 (A), and corn competing with cv. TEC 5718 or cv. TEC 6029 (B). Shoot dry mass (MSPA) of soybean and corn plants (C) and root dry mass (MSPR) of soybean cultivar plants, cv. TEC 5718 and TEC 6029 (D) under the following competition conditions: no competition (Null), soil resources + solar radiation (Total), solar radiation (Light) and soil resources (Soil).

differ in relation to the total competition or only for soil resources (Figure 2D). The null competition offered the highest production of MSPR, with 4.72 g per plant, however, it did not differ from the competition for soil resources and total competition: 4.35 and 4.47 g per plant, respectively.

When compared to the cultivars, it was observed that they behave differently when there was total competition with corn, where plants from cv. TEC 6029 produced a higher MSPR than cv. TEC 5718. However, when the competition occurred only for soil resources, plants from cv. TEC 5718 showed a higher MSPR in comparison to the ones from the other cultivar. In the situation in which the plants grew free from any type of competition, no difference was observed between the cultivars as to MSPR, and they also did not differ when they competed for light (Figure 2D).

For corn plants, the greater AF increment was obtained for the total competition condition and for the competition for soil resources (Table 4). A similar result was observed for the MSPR of corn plants: when they were in total competition or in competition only for soil resources, they showed an increment of 33 and 24%, respectively. For the chlorophyll index of corn, the lowest value was observed when plants grew in isolation.

The proximity to other plants in the environment causes physiological responses on the plants, which try to adapt to the stress condition through modulation and morphological expression, explaining, for example, the fact that the soybean plants produced higher MSPR when they competed with corn for soil resources. Depending on the development phase and the competition intensity, the relative importance of the

Table 4 - Leaf area (AF), root dry mass (MSPR) and chlorophyll index of corn plants in competition for environmental resources with soybean plants, cv. TEC 5718 and TEC 6029, 42 days after emergence (DAE). FAEM/UFPel, 2014/15

Competition conditions	AF (cm^2 per plant)	MSPR (g per plant)	Chlorophyll index
Null	778.92 b	5.71 b	24.30 b
Total	993.15 a	8.50 a	33.58 a
Solar radiation	781.92 b	5.77 b	35.60 a
Soil	1060.31 a	7.53 a	32.17 a
Mean	903.43	6.88	903.43
VC (%)[1/]	14.46	14.03	14.46

[1/] Variation coefficient. Means followed by different letters differ from each other according to Tukey's test (p≤0.05).

dispute for resources beneath and above the soil surface by the plants alternates (Bianchi et al., 2006).

When the plant searches for an environment free from light competition, it grows in height, however, the increase of the leaf mass is reduced, with less branches and thinner leaves, since the plant invests a major part of its photoassimilates to elongate the stem. When the competition occurs on the soil, the amount of water and nutrients available to the root system is limited, with a reduced shoot development. Therefore, a low production of MSPA, AF and reduced development of soybean DC occur under high levels of competition with corn plants, regardless of the condition of the competition. These results allow the conclusion that spontaneous corn plants in crops cause a strong competitive pressure on soybeans, both for light and soil, compromising their growth.

The water content on the soil, the availability of nutrients and the morphology of the roots simultaneously affect the competition between different species. The interactions between species beneath the soil may affect the productivity more than the interaction between species above the soil (He et al., 2012). Analyzing the competition of soybean cultivars with turnip for different resource conditions, it was observed that the competition for soil resources was higher than the competition for solar radiation, resulting in the reduction of the plant height, leaf area, shoot dry mass and the leaf mass ratio, as well as an increase on the specific leaf area and the leaf area ratio of soybeans (Bianchi et al., 2006).

In opposition to these results, a study evaluating the competition between rice and *Fimbristylis miliacea* plants concluded that the competition was higher for the weed when it occurred above the soil. This must have occurred possibly because the *F. miliacea* plants are shorter than rice plants. Therefore, *F. miliacea* plants are more impacted by the light competition than the competition for soil resources (Schaedler et al., 2015). In addition, since the root system of *F. miliacea* shallower, with thinner roots than rice, it may have partially avoided the competition on the rhizosphere.

On a study where the productivity of soybean on an intercrop with corn was evaluated, a lower production of soybeans was observed when it competed against corn both through the root system and the shoot (Lv et al., 2014). In addition, when the root system was separated, preventing the competition for soil resources, the soybean productivity was similar to the monoculture productivity, confirming that corn plants with the same density of soybeans are more competitive for resources beneath the soil, corroborating with the results obtained on this study.

The competition between soybean and corn plants is more pronounced for soil resources, when cultivars with low plant height and determined growth habit, such as TEC 5718, invest more in production of root dry mass, leaf area, specific leaf area and leaf area ratio, aiming at avoiding competition.

Soybean plants do not cause a suppressing effect on corn plants, and the latter are benefited when association to the root system of soybeans, with an increase on the shoot dry mass production, root dry mass, leaf area and chlorophyll index.

ACKNOWLEDGEMENTS

We thank to CNPq/CAPES for the scholarship, to colleagues Diego Fraga, Gabriel Klafke Gossler and Nixon Westendorff and also Dr. Mario Antonio Bianchi from CCGL Tec for his collaboration, providing the seeds of soybean cultivars.

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